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Research Article

# Detection and Analysis of Heart Rate during Arrhythmia

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**Abstract:** In this work, an algorithm has been developed for the analysis of heart rhythm and detection of sinus tachycardia, sinus bradycardia and atrial fibrillation. The proposed algorithm analysis the heart rhythm and heart rate of ECG dataset using P wave. The rhythm is identified regular with very high heart rate for sinus tachycardia, whereas very low heart rate for sinus bradycardia. The proposed algorithm detected the R-R intervals present in ECG data are irregular, and P wave is abnormal for atrial fibrillation. The results show that in normal ECG sample, the R-R interval of consecutive R peaks is normally constant and the variation in the heart rate is 7.5%. In the case of abnormal ECG sample, R-R intervals of consecutive R peaks changes significantly, and variation in the heart rate exceeded to 7.5% once in the ECG sample. In the case of sinus bradycardia, the rhythm is regular, and heart rate is less than 60, whereas in the case of sinus tachycardia, the rhythm is regular and heart rate is greater than 100. In the case of atrial fibrillation, irregular rhythm is observed and correlation coefficients of P wave are not more than 74%.

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## INTRODUCTION

ECG records the graphical activity of the Heart. P wave, R peak, RR interval, QRS complex and T wave are five important parameters in ECG (1). Sinus tachycardia and sinus bradycardia are associated with normal heart rhythm with high and low heart rate. In the case of atrial fibrillation, an abnormal heart rhythm is observed in which rapid and irregular heartbeats are found. Most of time, atrial fibrillation is responsible for heart failure (2). Other than heart failure, they may create some serious problem for the patient. Thus, detection of these diseases is very important at its earlier state for perfect treatment of these arrhythmias. Automatic detection of any physiological signal is the first step of an artificial intelligent based system to provide the assistance (3). Previously, many efforts have been made for the detection of Heart Rate variation. The normal ECG and Arrhythmias has been calculated by investigating the consecutive RR peaks in Arrhythmias (4). A. Ghodrati et al. detected irregularities in the RR interval for atrial fibrillation (5). RR-irregularities had measured by absolute deviation method and differences between two consecutive RR-intervals. S. Kodituwakku et al. perform time frequency analysis of AF. The algorithm has applied to simulate electrocardiogram with atrial fibrillation samples (6). ECG was generated by a method of the dynamical model. Generated ECG was reconstructing by removing P-waves and adding an atrial fibrillation signal. R. Shouldice et al. analyzed two intervals, PR interval and PP- interval (7). By an analysis of PP-intervals and PR-intervals under different conditions, independent and dependent nature of the automatic control of the two main cardiac pacemakers may be illuminated. J. Cauderc et al. analyzed the P-wave using morphology technique (8). P-wave segment was detected by taking 256 ms interval started from 355 ms to 100 ms before R-peak. Meyer's orthogonal wavelet transformation had used to divide 256ms into 255-wavelet coefficient. Further, the de-noising of ECG data may improve the better detection of heart rhythm. Previously, many filters have been proposed for de-noising of biological signals (9-11). The de-noising of data suppress the noise, however, degrades the information contents of the signal. Recently, a prospective technique has been developed where noise can be utilized to enhance the information of the signal, called stochastic resonance (SR) (12). Further, the ECG data can be adaptively de-noise using optimized SR (13-16).

The motivation of the present work is to develop an algorithm to detect Sinus tachycardia, sinus bradycardia and atrial fibrillation that could be applied to clinical practice as a diagnostic test. The major objective for the design of the detection method is to create a framework that would detect patient's electrocardiogram (ECG) that have characteristics of sinus tachycardia and sinus bradycardia. This was achieved by heart rhythm analysis and analysis of P-wave, QRS complex ST segment and T-wave. The organization of present article as follows. The material and methods section shows framework and experimentation. Section 3 shows the results obtained using proposed algorithm. Finally, section 4 concludes the proposed work.

## MATERIAL AND METHODS

Sinus tachycardia related to high heart rate while sinus bradycardia is due to low heart rate. Atrial fibrillation is due to the rapid rate of atrial depolarization. In the case of atrial fibrillation atrial contraction take place very fast, electric heart rhythm is irregular and hence, the P-wave get disturbed.

Features of detection of sinus tachycardia and sinus bradycardia are: (i) Regular heart rhythm, (ii) Normal P-wave, (iii) High or low heart rate. Features for the detection of atrial fibrillation are: (i) Irregular heart rhythm, (ii) Disturbed P-wave.

### Heart Rhythm Analysis and Heart Rate Calculation

RR intervals are used to calculate the heart rate and analyze the heart rhythm. Heart rate can calculate by calculating R peaks in one minute. Fig. 1 shows the block diagram of heart rhythm analysis. The proposed algorithm is used to detect consecutive RR intervals. This experiment considered seven consecutive R peaks for the detection of variation in the heart rate, which is further used to detect the Arrhythmia. The proposed algorithm is tested on ECG obtained from MIT-BIH normal sinus rhythm database (nsrdb) and Physiobank intracardiac atrial fibrillation database (iafdb) (17, 18).

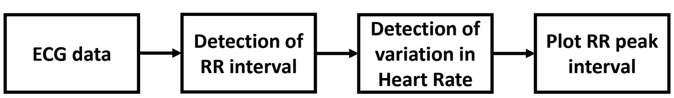


**Fig. 1** Block diagram of Heart rhythm analysis

### Detection of P-wave

Detection of P-wave is important for the analysis of AF. P – wave can be detected by taking ECG sample from 350 ms to 50 ms before R peak (19). First, extract P-wave from standard normal ECG, and then detects P-wave of ECG under test. AF can be determined using the cross correlation between standard P-wave and detected P-wave.

### Detection of Sinus Tachycardia, Bradycardia & Atrial Fibrillation

For analysis of Tachycardia, Bradycardia and Atrial fibrillation, we need ECG sampled data, which are taken from Physiobank database. Figure 2 shows the flow chart for the detection of Tachycardia, Bradycardia and AF. First, Heart rate is calculated from given ECG sample. After calculation of heart rate, rhythm of heart rate is calculated. There are two conditions in the rhythm analysis: (i) Regular rhythm, (ii) Irregular rhythm.

*Regular rhythm*

If the rhythm is regular, there are three conditions: (a) Normal ECG when the heart rate is between 60 to 100; (b) Sinus Bradycardia when the heart rate is less than 60 and (c) Sinus Tachycardia when the heart rate is greater than 100.

*Irregular rhythm*

RR- intervals were chosen as to analyze from ECG data for atrial fibrillation, as this was the noticeable difference on the ECG for fibrillation patients. This experiment also examines RR-intervals for atrial fibrillation, since it has been observed that the most of the patient data contained patterns of irregularities. If the rhythm is irregular, then we calculate the correlation between standard P-wave and seven consecutive P-waves of ECG under test (20).

If the correlation of three P-waves out of seven consecutive P-waves is less than 74%, then there is atrial fibrillation. Since the P-waves have much lower amplitudes than R-peaks and are easily impacted by noise. This can affect the accuracy of the algorithm (21). In normal ECGs, the RR-intervals will change based on the current state of the patient. While being monitored, the patient may be sleeping, exercising, stressed, resting or subjected to something else that may cause a change in variability that does not attribute to a heart arrhythmia. Thus, compared individual RR-intervals and test for their variability, rather than looking at the entire data set as a whole.

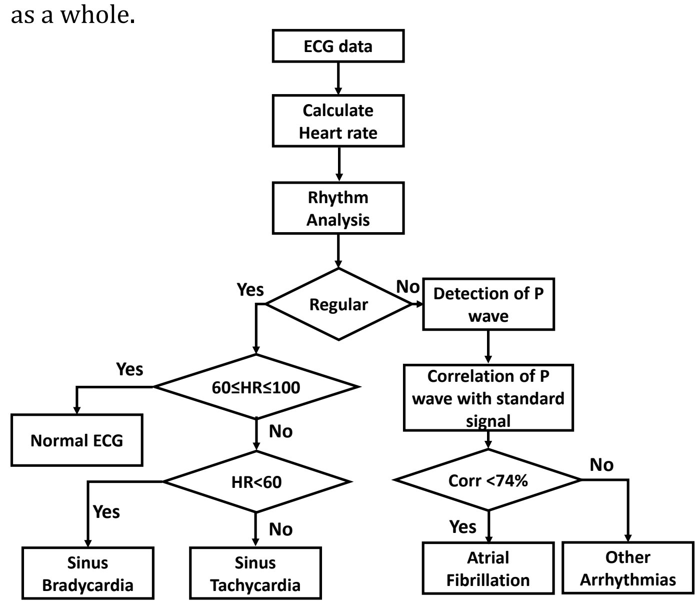


**Fig. 2** Flow chart for detection of Atrial Fibrillation HR

## RESULTS AND DISCUSSION

The performance of the algorithm is evaluated on four databases. These four databases are MIT-BIH normal sinus rhythm database (nsrdb), Superventricular, Arrhythmia database (svdb), atrial fibrillation database (afdb), and Arrhythmia database (adb). In MIT- BIH normal sinus rhythm database, super ventricular arrhythmia database and Atrial fibrillation ECGs are sampled at 128 Hz while

Sampling rate in MIT-BIH Arrhythmia database is 360 Hz. MIT- BIH normal sinus rhythm database contains 48 half-hour excerpts of two channel ambulatory ECG recording.

Tables (1 to 6) provide the result related to various ECG beats analysis using proposed algorithm. The RR intervals measure digitized ECG signals, which were first processed to detect the R wave and its position (22, 23). This process is further repeated for recognition of next R peak and its position. The RR interval can be calculated as given follows:

$$\text{RR interval} = d_{PP} * \text{sampling time}$$

*Where* $d_{PP}$ is the position difference between two consecutive R peaks. If rhythm is irregular, then it may be Atrial Flutter, or Atrial Fibrillation, or sinus Arrest (19). PP or RR intervals are frequently used in heart rate variability study.

**Table 1** Analysis of normal ECG

| ECG No. | R12 Samples | HR1 Bpm | R23 Samples | HR2 Bpm | R34 Samples | HR3 Bpm | R45 Samples | HR4 Bpm | R56 samples | HR5 Bpm | R67 samples | HR6 Bpm |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| 17052 | 114 | 67.3 | 115 | 66.7 | 110 | 69.8 | 110 | 69.8 | 116 | 66.20 | 113 | 65.08 |
| 16795 | 107 | 71.7 | 112 | 68.5 | 114 | 67.3 | 123 | 62.4 | 121 | 63.47 | 117 | 65.64 |
| 16786 | 108 | 71.1 | 110 | 69.8 | 103 | 74.5 | 108 | 71.1 | 111 | 69.18 | 107 | 71.77 |
| 16539 | 96 | 80 | 99 | 77.5 | 96 | 80 | 90 | 85.3 | 89 | 86.33 | 94 | 86.29 |
| 16483 | 81 | 94.8 | 79 | 97.2 | 79 | 97.2 | 80 | 96 | 80 | 96 | 80 | 96 |
| 16420 | 81 | 94.8 | 79 | 97.2 | 82 | 93.6 | 82 | 93.6 | 78 | 98.46 | 79 | 97.21 |
| 16272 | 125 | 61.44 | 123 | 62.43 | 123 | 62.43 | 122 | 62.95 | 123 | 62.43 | 125 | 61.44 |
| 16273 | 78 | 98.4 | 77 | 99.7 | 77 | 99.7 | 78 | 98.4 | 78 | 98.46 | 79 | 97.21 |
| 16265 | 77 | 99.7 | 78 | 98.5 | 77 | 99.7 | 79 | 97.2 | 79 | 97.21 | 79 | 99.74 |

R12- Sample difference between first and second R peak, HR1- Heart rate calculated by R12, R23- Sample difference between second and third R peak, HR2- Heart rate calculated by R23, R34- Sample difference between third and fourth R peak, HR3- Heart rate calculated by R34, R45- Sample difference between fourth and fifth R peak, HR4- Heart rate calculated by R45

**Table 2** Variation in RR peak interval in normal ECG

| ECG No | HRav Bpm | % ( HR1)v | % ( HR2)v | % ( HR3)v | % ( HR4)v | % ( HR5)v | % ( HR6)v |
|---|---|---|---|---|---|---|---|
| 17052 | 67.99 | 1.01 | 1.89 | 2.66 | 2.66 | 2.63 | 4.28 |
| 16795 | 66.54 | 7.75 | 2.94 | 1.14 | 6.22 | 4.61 | 1.35 |
| 16786 | 71.26 | 0.22 | 2.04 | 4.54 | 0.22 | 2.91 | 0.71 |
| 16539 | 81.81 | 2.21 | 14.68 | 2.21 | 4.26 | 5.52 | 5.47 |
| 16483 | 96.20 | 1.45 | 1.03 | 1.03 | 0.20 | 0.20 | 0.20 |
| 16420 | 98.68 | 3.93 | 1.49 | 5.14 | 5.14 | 0.22 | 1.48 |
| 16272 | 62.19 | 1.20 | 0.38 | 0.38 | 1.22 | 0.38 | 1.20 |
| 16273 | 98.68 | 0.28 | 1.03 | 1.03 | 0.28 | 0.22 | 1.48 |
| 16265 | 98.26 | 1.46 | 0.24 | 1.44 | 1.07 | 1.06 | 1.50 |

HRav =Average heart rate calculated from five RR intervals, HRav =(HR1+HR2+HR3+HR4+HR5+HR6)/6, %(HR1)v- % variation in HR1 from HRav, %(HR2)v- % variation in HR2 from HRav, %(HR3)v- % variation in HR3 from HRav, %(HR4)v- % variation in HR4 from HRav, %(HR5)v- % variation in HR5 from HRav, %(HR6)v- % variation in HR6 from HRav

**Table 3** Analysis of Arrhythmia for suspected sinus tachycardia sinus bradycardia

| ECG No. | R12 Sample | HR1 Bpm | R23 Sample | HR2 bpm | R34 Sample | HR3 bpm | R45 Sample | HR4 Bpm | R56 Sample | HR5 Bpm | R67 Sample | HR6 Bpm |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| 800 | 168 | 45.71 | 167 | 45.98 | 169 | 45.44 | 170 | 45.44 | 166 | 46.26 | 169 | 45.44 |
| 811 | 165 | 46.54 | 162 | 47.40 | 161 | 47.70 | 161 | 47.70 | 314 | 24.45 | 158 | 48.60 |
| 821 | 74 | 103.78 | 73 | 105.40 | 75 | 102.40 | 74 | 103.78 | 74 | 103.78 | 56 | 137.14 |
| 823 | 80 | 96 | 80 | 96 | 81 | 94.81 | 79 | 97.21 | 79 | 97.21 | 79 | 97.21 |
| 4043 | 139 | 107.91 | 141 | 106.38 | 141 | 106.38 | 139 | 107.91 | 138 | 108.69 | 141 | 108.38 |
| 7910 | 258 | 58.13 | 259 | 57.91 | 260 | 57.69 | 259 | 57.91 | 259 | 57.97 | 260 | 57.69 |
| 823(2) | 80 | 96 | 81 | 94.81 | 80 | 96 | 80 | 96 | 78 | 98.46 | 80 | 96 |
| 14046 | 105 | 73.14 | 103 | 74.56 | 100 | 76.80 | 99 | 77.57 | 616 | 12.46 | 103 | 74.56 |
| 124 | 449 | 48.10 | 426 | 50.70 | 434 | 49.76 | 436 | 49.47 | 455 | 47.47 | 441 | 48.97 |

**Table 4** Variation in RR peak interval in Arrhythmias

| ECG No | HRav bpm | % ( HR1)v | % ( HR2)v | % ( HR3)v | % ( HR4)v | % ( HR5)v | % ( HR6)v |
|---|---|---|---|---|---|---|---|
| 800 | 45.67 | 0.08 | 0.67 | 0.50 | 0.50 | 1.29 | 0.50 |
| 811 | 43.73 | 6.42 | 8.39 | 9.07 | 9.07 | 11.13 | 11.13 |
| 821 | 109.34 | 5.08 | 3.60 | 6.34 | 5.08 | 5.08 | 25.42 |
| 823 | 96.41 | 0.42 | 0.42 | 1.65 | 0.82 | 0.82 | 0.82 |
| 4043 | 107.27 | 0.59 | 0.82 | 0.82 | 0.59 | 1.32 | 1.03 |
| 7910 | 57.87 | 0.40 | 0.06 | 0.31 | 0.06 | 0.15 | 0.31 |
| 823(2) | 89.45 | 7.32 | 9.44 | 5.99 | 5.99 | 10.07 | 7.32 |
| 14046 | 64.85 | 12.78 | 14.97 | 18.42 | 19.61 | 1.54 | 14.97 |
| 124 | 49.09 | 2.01 | 3.27 | 1.36 | 0.77 | 3.30 | 0.24 |

**Result of Analysis for Atrial Fibrillation**

ECG data from physiobank have used in the analysis of atrial fibrillation. Samples are mainly taken from AF terminal challenge and MIT-BIH normal sinus rhythm database (NSRDB). The arrhythmia analyses have done in case of atrial fibrillation as shown in Table 5. The correlation between two healthy samples: 16786 and 16272 with thirteen AF samples has been obtained, which is given in Table 6 and Table 7 respectively. It can be noted in Table 6 and Table 7 that the correlation could not be obtained for standard P-wave and first P-wave of few samples (-) because first P-wave of ECG under could not be detected.

**Table 5** Analysis of Arrhythmia

| ECG No. | R12 Sample | HR1 Bpm | R23 Sample | HR2 Bpm | R34 Sample | HR3 Bpm | R45 Sample | HR4 Bpm | R56 Sample | HR5 Bpm | R67 Sample | HR6 Bpm |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| n/02 | 98 | 78.36 | 93 | 82.58 | 95 | 80.84 | 115 | 66.78 | 99 | 77.57 | 90 | 85.33 |
| n/04 | 97 | 79.17 | 68 | 112.94 | 76 | 101.05 | 101 | 76.03 | 78 | 98.46 | 73 | 105.20 |
| n/05 | 121 | 63.47 | 79 | 97.21 | 79 | 97.21 | 81 | 94.81 | 99 | 77.57 | 68 | 112.94 |
| n/06 | 92 | 83.47 | 64 | 120 | 160 | 48 | 143 | 53.70 | 102 | 75.29 | 127 | 60.47 |
| n/07 | 141 | 54.46 | 33 | 232.72 | 101 | 76.03 | 33 | 232.72 | 68 | 132.41 | 128 | 60 |
| n/08 | 65 | 118.15 | 69 | 111.30 | 89 | 86.29 | 86 | 89.30 | 72 | 106.66 | 94 | 81.70 |
| n/09 | 109 | 70.45 | 87 | 88.27 | 97 | 79.17 | 93 | 82.58 | 128 | 60 | 99 | 77.57 |
| s/02 | 87 | 134.7 | 89 | 86.29 | 60 | 128 | 83 | 92.53 | 53 | 144.90 | 53 | 144.90 |
| s/03 | 90 | 85.33 | 129 | 59.53 | 124 | 601.93 | 148 | 51.89 | 155 | 61.44 | 112 | 68.57 |
| b/11 | 83 | 92.53 | 157 | 48.91 | 133 | 57.74 | 151 | 50.86 | 56 | 137.14 | 194 | 39.58 |
| b/12 | 104 | 73.84 | 60 | 128 | 48 | 160 | 46 | 166.95 | 48 | 160 | 44 | 174.54 |
| b/13 | 88 | 87.27 | 65 | 118.15 | 73 | 105.20 | 59 | 130.16 | 137 | 56.05 | 59 | 130.16 |
| b/15 | 99 | 77.57 | 99 | 77.57 | 111 | 69.18 | 101 | 76.03 | 108 | 71.11 | 110 | 69.81 |

**Table 6** Correlation table between first P-wave of 16786 with AF samples

| AF Samples | %R1 | %R2 | %R3 | %R4 | %R5 | %R6 | %R7 |
|---|---|---|---|---|---|---|---|
| n/02 | - | 27.84 | 29.39 | 34.98 | 42.83 | 34.07 | 69.34 |
| n/04 | 28.25 | 13.75 | 13.67 | 31.50 | 38.40 | 22.86 | 26.73 |
| n/05 | - | 63.18 | 10.27 | 18.47 | 13.66 | 11.62 | 12.11 |
| n/06 | 29.58 | 46.12 | 13.98 | 29.10 | 29.84 | 30.33 | 40.33 |
| n/07 | 35.35 | 60.71 | 52.88 | 69.21 | 33.58 | 107.27 | 69.28 |
| n/08 | - | 5.85 | 24.27 | 55.52 | 49.68 | 26.17 | 28.22 |
| n/09 | - | 62.07 | 43.01 | 18.71 | 9.32 | 10.52 | 11.40 |
| s/02 | - | 13.77 | 43.71 | 71.81 | 55.94 | 79.64 | 30.51 |
| s/03 | 45.83 | 52.66 | 61.84 | 46.84 | 58.61 | 51.08 | 44.36 |
| b/11 | 4.47 | 3.00 | 2.83 | 12.33 | 12.06 | 0.96 | 48.26 |
| b/12 | - | 40.83 | 35.23 | 53.29 | 59.63 | 65.65 | 54.87 |
| b/13 | - | 52.38 | 64.86 | 42.96 | 61.95 | 52.17 | 47.14 |
| b/15 | - | 40.75 | 35.93 | 46.03 | 36.68 | 32.69 | 26.59 |

**Table 7** Correlation table between first P-wave of 16272 with AF samples

| AF Samples | %R1 | %R2 | %R3 | %R4 | %R5 | %R6 | %R7 |
|---|---|---|---|---|---|---|---|
| n/02 | 30.10 | 26.74 | 24.24 | 28.88 | 37.53 | 30.01 | 59.38 |
| n/04 | 21.87 | 13.76 | 13.71 | 34.94 | 34.42 | 18.95 | 26.41 |
| n/05 | - | 60.83 | 9.54 | 17.34 | 11.34 | 10.63 | 12.05 |
| n/06 | 28.52 | 40.03 | 13.41 | 26.29 | 24.89 | 24.25 | 35.80 |
| n/07 | 30.07 | 47.64 | 47.79 | 54.85 | 34.79 | 95.26 | 58.16 |
| n/08 | - | 5.61 | 23.84 | 45.97 | 44.24 | 27.92 | 26.87 |
| n/09 | - | 59.49 | 41.54 | 15.23 | 10.21 | 11.33 | 7.26 |
| s/02 | - | 6.51 | 47.95 | 62.43 | 48.58 | 70.39 | 30.68 |
| s/03 | 39.39 | 45.50 | 52.47 | 48.75 | 39.31 | 44.13 | 39.23 |
| b/11 | 2.66 | 2.93 | 2.78 | 10.30 | 10.72 | 1.04 | 42.99 |
| b/12 | - | 47.85 | 20.91 | 59.19 | 42.72 | 61.56 | 54.76 |
| b/13 | - | 46.98 | 63.43 | 44.02 | 55.90 | 43.03 | 47.24 |
| b/15 | - | 45.95 | 33.74 | 36.83 | 35.39 | 33.44 | 31.11 |

%R1 is the correlation percentage between standard P-wave and first P-wave of ECG under test, %R2 is the correlation percentage between standard P-wave and second P-wave of ECG under test, %R3 is the correlation percentage between standard P-wave and third P-wave of ECG under test, %R4 is the correlation percentage between standard P-wave and fourth P-wave of ECG under test, %R5 is the correlation percentage between standard P-wave and fifth P-wave of ECG under test, %R6 is the correlation percentage between standard P-wave and Sixth P-wave of ECG under test, %R7 is the correlation percentage between standard P-wave and seventh P-wave of ECG under test.

## CONCLUSIONS

This study concludes that in the case of normal ECGs, RR interval is almost constant in consecutive R peaks and the average variation in heart rate variation (%Hn) is 7.5%. On the other side, in the case of abnormal ECGs, RR intervals in consecutive R peaks changed significantly. Heart rate variation (%Hn) exceeded by 7.5% from calculated average heart rate (HRav) at least one time in ECG strip. The heart rhythm has been found irregular during the analysis of atrial fibrillation, and the correlation coefficients are comparatively low. The correlation coefficients are not exceeding 74%. If correlation coefficients exceed to 74%, then there is no atrial fibrillation. The implemented algorithm has been successfully detected the atrial fibrillation, with high accuracy, and requires a simple user interface.

## REFERENCES


1. Pan J, Tompkins WJ. A real-time QRS detection algorithm. IEEE transactions on biomedical engineering. 1985(3):230-6.
2. Kannel WB, Wolf PA, Benjamin EJ, Levy D. Prevalence, incidence, prognosis, and predisposing conditions for atrial fibrillation: population-based estimates. The American journal of cardiology. 1998;82(7):2N-9N.
3. Singh M, Verma R, Kumar G, Singh S. Machine perception in biomedical applications: an introduction and review. Journal of Biological Engineering Research and Review. 2014;1(2):20-5.
4. Tripathi A, Ayub S, editors. Heart Rate Variability Detection in Arrhythmia. Computational Intelligence and Communication Networks (CICN), 2015 International Conference on; 2015: IEEE.
5. Ghodrati A, Murray B, Marinello S, editors. RR interval analysis for detection of atrial fibrillation in ECG monitors. Engineering in Medicine and Biology Society, 2008 EMBS 2008 30th Annual International Conference of the IEEE; 2008: IEEE.
6. Kodituwakku S, Kennedy RA, Abhayapala TD, editors. Time-frequency analysis compensating missing data for Atrial Fibrillation ECG assessment. Acoustics, Speech and Signal Processing (ICASSP), 2011 IEEE International Conference on; 2011: IEEE.
7. Shouldice R, Heneghan C, Nolan P, Nolan P, editors. PR and PP ECG intervals as indicators of autonomic nervous innervation of the cardiac sinoatrial and atrioventricular nodes. Neural Engineering, 2003 Conference Proceedings First International IEEE EMBS Conference on; 2003: IEEE.
8. Couderc J, Fischer S, Costello A, Daubert J, Konecki J, Zareba W, editors. Wavelet analysis of spatial dispersion of P-wave morphology in patients converted from atrial fibrillation. Computers in Cardiology, 1999; 1999: IEEE.
9. Uvanesh K, Nayak SK, Champaty B, Thakur G, Mohapatra B, Tibarewala D, et al. Classification of Surface Electromyogram Signals Acquired from the Forearm of a Healthy Volunteer. Classification and Clustering in Biomedical Signal Processing: IGI Global; 2016. p. 315-33.
10. Kabir MA, Shahnaz C. Denoising of ECG signals based on noise reduction algorithms in EMD and wavelet domains. Biomedical Signal Processing and Control. 2012;7(5):481-9.
11. Tracey BH, Miller EL. Nonlocal means denoising of ECG signals. IEEE transactions on biomedical engineering. 2012;59(9):2383-6.
12. Benzi R, Sutera A, Vulpiani A. The mechanism of stochastic resonance. Journal of Physics A: mathematical and general. 1981;14(11):L453.
13. Singh M, Verma A, Sharma N. Optimized multi-stable stochastic resonance for the enhancement of pituitary micoadenoma in MRI. IEEE Journal of Biomedical and Health Informatics. 2017. (DOI:10.1109/JBHI.2017.2715078)
14. Singh M, Sharma N, Verma A, Sharma S. Dynamic Stochastic Resonance Based Diffusion-Weighted

Magnetic Resonance Image Enhancement Using Multi-Objective Particle Swarm Optimization. Journal of Medical and Biological Engineering. 2016;36(6):891-900. (DOI: 10.1007/s40846-016-0186-0)
15. Singh M, Verma A, Sharma N. Bat optimization based neuron model of stochastic resonance for the enhancement of MR images. Biocybernetics and Biomedical Engineering. 2017;37(1):124-34. (DOI: 10.1016/j.bbe.2016.10.006)
16. Singh M, Sharma S, Verma A, Sharma N. Enhancement and Intensity Inhomogeneity Correction of Diffusion-Weighted MR Images of Neonatal and Infantile Brain Using Dynamic Stochastic Resonance. Journal of Medical and Biological Engineering. 2017. (DOI: 10.1007/s40846-017-0270-0)
17. Moody GB, Mark RG. The impact of the MIT-BIH arrhythmia database. IEEE Engineering in Medicine and Biology Magazine. 2001;20(3):45-50.
18. Goldberger AL, Amaral LA, Glass L, Hausdorff JM, Ivanov PC, Mark RG, et al. Physiobank, physiotoolkit, and physionet. Circulation. 2000;101(23):e215-e20.
19. Trivedi P, Ayub S, editors. Detection of R Peak in Electrcardiogram. IJCA; 2014.
20. Saxena S, Sharma A, Chaudhary S. Data compression and feature extraction of ECG signals. International Journal of Systems Science. 1997;28(5):483-98.
21. Chiu C-C, Lin T-H, Liau B-Y. Using correlation coefficient in ECG waveform for arrhythmia detection. Biomedical Engineering: Applications, Basis and Communications. 2005;17(03):147-52.
22. Gholinezhadasnefestani S, Escalona O, Nazarzadeh K, Kodoth V, Lau E, Manoharan G, editors. QRST cancellation in ECG signals during atrial fibrillation: Zero-padding versus time alignment. Signal Processing and Communication Systems (ICSPCS), 2012 6th International Conference on; 2012: IEEE.
23. Beckers F, Anné W, Verheyden B, de Kestergat CvdD, Van Herk E, Janssens L, et al., editors. Determination of atrial fibrillation frequency using QRST-cancellation with QRS-scaling in standard electrocardiogram leads. Computers in Cardiology, 2005; 2005: IEEE.

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